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Economic Viability Report for Abyssal Plains Waste Isolation Project

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The Department of Defense's Naval Research Laboratory (NRL) has been tasked by the Strategic Environmental Research and Development Program (SERDP) to study environmental viability of the storage of dredged materials, sewage sludge, and municipal incinerator fly ash in the abyssal plains of the ocean floor. Abyssal Plains Waste Isolation (APWI) is the term given by this project to the storage of waste in the abyssal plains. Oceaneering Technologies (OTECH) has been tasked by NRL to assess waste handling technologies regarding engineering feasibility and reliability.

This economic viability report estimates both the capital costs and the annual operating costs of technically viable APWI concepts. By estimating these costs, APWI system concepts can be compared to existing isolation methods to examine the overall viability of the APWI approach. In addition, comparisons are made between the APWI system concepts to see if the most economically viable system is evident.

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ABSTRACT

The Department of Defense's Naval Research Laboratory (NRL) has been tasked by the Strategic Environmental Research and Development Program (SERDP) to assess the environmental viability of the isolation of dredged material, sewage sludge, and municipal incinerator fly ash on the abyssal plains of the ocean floor. Abyssal Plains Waste Isolation (APWI) is the term given by this project to the isolation of waste on the abyssal seafloor. Oceaneering Technologies (OTECH) has been tasked by NRL to assess waste handling technologies regarding engineering feasibility and reliability.

This economic viability report estimates both the capital costs and the annual operating costs of technically viable APWI concepts. By estimating these costs, APWI system concepts can be compared to existing isolation methods to examine the overall viability of the APWI approach. In addition, comparisons are made between the APWI system concepts to see if the most economically viable system is evident.

This economic viability report is the third in a series of three reports submitted to NRL by OTECH. The first report covered the system level requirements which are requirements all APWI concepts must meet (Marcy et al. 1994). The second was the technical assessment report which defined and evaluated APWI concepts (Hightower et al., in publication).

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1.0 SUMMARY

Four Abyssal Plains Waste Isolation concepts were identified during the technical assessment phase of this study that provide technically feasible approaches for isolation of contaminated dredged materials, sewage sludge, and municipal incinerator fly ash. In addition, these four concepts can be engineered to meet all the performance/operational system level requirements identified in the first part of this study. In this report, these four concepts' capital and annual costs were analyzed. The results of this costing exercise will be used to:

- Compare costs between APWI concepts to identify optimal concept(s) or to identify concept(s) that are not economically viable.

- Assess the viability of the APWI approach by comparing the concept's emplacement costs to existing isolation methods.

As a result of the costing exercise, the annual cost for each concept, and the cost per cubic meter of dredged material emplaced, and cost per metric ton of sewage sludge and fly ash emplaced are as follows:

- Surface Emplacement - Concept annual cost is $15 million. Emplacement cost of dredged material is $16/cubic meter ($12/cubic yard), and of sewage sludge and fly ash is $15/metric ton.

- ROV Glider - Concept annual cost is $25 million. Emplacement cost of dredged material is $21/cubic meter ($16/cubic yard), and of sewage sludge and fly ash is $20/metric ton.

- Direct Descent Disk - Concept annual cost is $32 million. Emplacement cost of dredged material is $26/cubic meter ($20/cubic yard); and of sewage sludge and fly ash is $24/metric ton.

- Pipe Riser - Total annual cost is $11 million. Emplacement cost of dredged material is $20/cubic meter ($15/cubic yard), and of sewage sludge and fly ash is $18/metric ton.

Do note, the estimated costs reported in this report are those costs from the port-of-loading to the abyssal seafloor waste isolation site. Those costs of handling and transporting these wastes from source to port are not included herein: for source-to-port estimated costs see Di Jin et al. (in publication).

2.0 INTRODUCTION

The Strategic Environmental Research and Development Program (SERDP) tasked the Naval Research Laboratory (NRL) to assess the advantages, disadvantages, and environmental viability of storing dredged material, sewage sludge, and municipal incinerator fly ash on the abyssal plains of the ocean. This study is called the Abyssal Plains Waste Isolation (APWI) Project. NRL has six objectives in assessing the isolation of waste on the abyssal plains.

1. Identify environmental characteristics of the abyssal seafloor which impact on its suitability for waste isolation;

2. Select abyssal seafloor areas possessing environmental characteristics compatible with waste isolation;

3. Assess the engineering feasibility and reliability of candidate waste handling technologies;

4. Develop a survey plan to obtain a baseline of the physical, chemical, biological, and geological characteristics of a suitable area;

5. Prepare a monitoring program plan; and

6. Conduct an economic analysis of the deep ocean isolation concepts.

Oceaneering Technologies (OTECH) has been tasked by NRL to assess waste handling technologies as to engineering feasibility and reliability, which is objective number three above. OTECH has further broken down this objective into three tasks:

1. System Requirements

2. Technical Assessment

3. Economic Viability

This report deals only with task number three, economic viability. The economic viability report estimates both capital and annual costs for each of the following four technically viable APWI concepts identified in the technical assessment report (Hightower et al., in publication):

- Surface Emplacement
- ROV Glider
- Direct Descent Disk
- Pipe Riser

Figure 2.0-1 shows the relationship of these task reports as related to OTECH's system engineering technical approach. The shaded area includes information presented in this report.

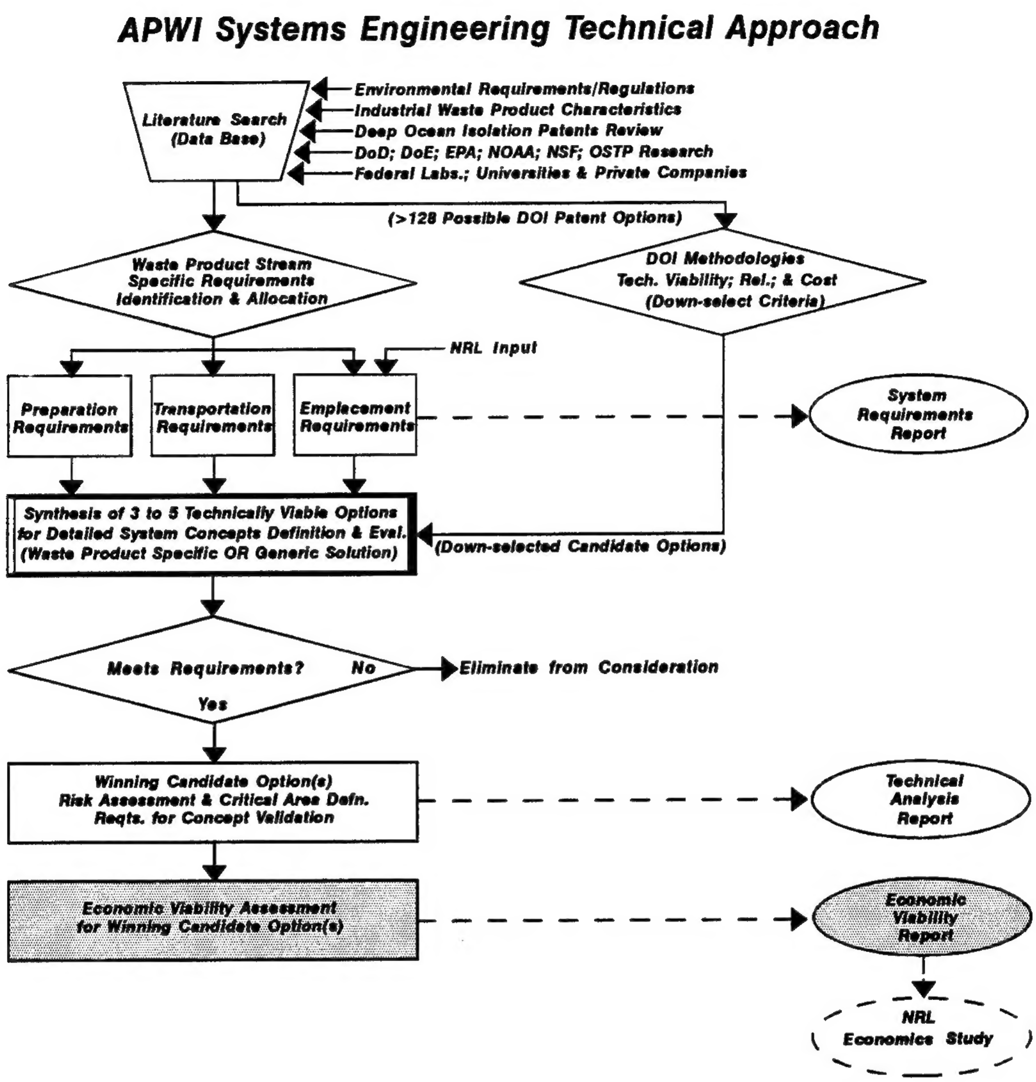

Figure 2.0-1
APWI Systems Engineering Approach

3.0 METHODS AND ASSUMPTIONS

The following four concepts were determined to be technically viable alternatives for deep ocean isolation of waste on the abyssal sea floor:

- Surface Emplacement - A customized barge designed with 51 separate cells, which are lined with disposable, high strength, high density, flexible fabric bags. The waste material is loaded into the individual bags and the bags closed while in port. The vessel then transits to the APWI site, opens the trap doors to the cells to release the bags, which free-fall to the seabed. The bag isolates the material from the intervening water column during descent. After landing on the bottom, the material remains contained in the bag. Experiments conducted by the U.S. Army Corps of Engineers has demonstrated that these types of bags do not burst upon landing on the seafloor.

- ROV Glider - A submersible, remotely operating vessel (ROV) Glider is used to transport material to the abyssal isolation site, submerge, release it at a specified altitude, and return back to the surface for recovery. Similar to the Surface Emplacement concept, the ROV Glider concept contains individual compartments lined with flexible bags. The Glider is negatively buoyant when loaded with waste, so it is towed to the APWI site in a floating "garage". At the site, the ROV Glider is released from its "garage". The Glider descends in an actively controlled straight or spiral-shaped glide path until it nears the sea floor. Near the seafloor, its trap doors open, the containerized load falls out, and the now positively buoyant Glider returns to the surface. The ROV Glider is then recovered by the surface ship into its "garage." The ROV Glider is autonomously controlled, but can be minimally controlled from the surface as a backup mode.

- Direct Descent Disk - A vessel in the shape of a large diameter, shallow disk delivers its cargo to a predetermined altitude off the sea floor and then releases it. The disk also has numerous cargo cells lined with bags. It is negatively buoyant when loaded with waste. It is towed to the site and, when released, descends in a near-vertical path to near the sea floor, brakes, releases its containerized load via trap doors, becomes positively buoyant, and ascends to the surface. In contrast to the ROV Glider, the Direct Descent Disk does not follow a closed-loop controlled glidepath. Its inherently stable hydrodynamic design allows it to perform the operation without active stabilization.

- Pipe Riser - A set of four large diameter pipes run vertically from the ocean surface to near the sea floor to transport waste to the abyssal isolation site. A transport ship hauls the waste material in bulk from the port to the APWI site, where it is pumped to the riser for dilution with cold water prior to emplacement. Two pipes bring cold water from abyssal depths to slurryize and thermally equalize the waste with the abyssal water. The slurryized waste travels down the other two pipes, isolating it from the water column. The waste is discharged near the seafloor forming a mound on the sea floor. The pipe riser is dynamically positioned at the top and moored at the bottom to maintain station.

3.1 NONRECURRING EXPENSES

Nonrecurring Expenses are defined as those capital expenses which will not be repeated for the life of that system. For the APWI concepts, nonrecurring expenses for a new build include:

- Engineering Design
- Shipyard Production Engineering
- Material Acquisition
- Shipyard Manufacturing
- Builder's Trial, Certificate of Fitness, and Classification
- Port Facilities

These costs were based on the following assumptions and background information.

3.1.1 ENGINEERING DESIGN

Engineering design is necessary to provide system level specifications, including subsystem specifications, source control drawings and interface control drawings. The design cost in manhours is typically equal to approximately 33% of the total estimated shipyard production engineering manhours. These Naval Architectural engineering design manhour estimates were provided by John J. McMullen and Associates (JJMA), a Naval Architecture firm, after review of the four concept configurations (in Hightower et al., in publication, Appendix C). The estimated engineering cost is $60.00 per manhour (/MH).

3.1.2 SHIPYARD PRODUCTION ENGINEERING

Shipyard Production Engineering costs are those engineering costs associated with a "New-build". For each APWI concept, the amount of shipyard engineering manhours to produce both self-propelled and unmanned vessels were researched for comparison. Based on costs provided by JJMA, the engineering labor for a new-build can be estimated at less than or equal to 100,000 manhours for a self-propelled bulk carrier/transport (or Tug), and less than or equal to 50,000 manhours for an unmanned variant (Integrated Tug/Barge). The estimated shipyard engineering cost is $33.60/MH.

3.1.3 MATERIAL ACQUISITION

The materials used for building either of the transport vessels (self-powered or unmanned) as well as the unique elements of the APWI concepts include:

- Steel
- Aluminum
- Foam (Syntactic, Hysin type 55)
- Propulsion and Electric Plant
- Electronic Subsystems
- Fluid Systems
- Remainder of Outfit

Steel and Aluminum costs, on a per ton basis, were provided by JJMA and are $1000/ton and $2500/ton respectively. Syntactic foam costs on a per ton basis, were derived from OTECH experience in building deep sea Remotely Operated Vehicles (ROVs), yielding a cost of $14,700/ton ($7950/cubic meter). Similarly, OTECH also used its ROV experience to price the Submersible Electric Plants at $25,000/ton and Electronic Subsystems at $250,000 to $1 million/system, depending on the complexity. Surface Vessel Propulsion and Electric Plant costs, on a per ton basis, were provided by JJMA. They are based upon a cost of $5500/ton, with fluid systems estimated at $2500/ton and the remainder of the outfitting estimated at $3000/ton. For the Pipe Riser, the remainder of outfit includes the nonmetallic structural platforms, a 12,000 gallon mixing chamber, and low density syntactic foam at the surface for flotation.

3.1.4 SHIPYARD MANUFACTURING

Shipyard manufacturing rates were also provided by JJMA and are estimated on a per ton basis. Structural manufacturing cost for any vessel is estimated at 75 manhours/ton; manufacturing cost for machinery installation is estimated at 200 manhours/ton; fluid systems installation cost is estimated at 250 manhours/ton; and the manufacturing costs for the remainder of the outfitting estimated at 150 manhours/ton. The estimated shipyard labor cost is $33.60/MH.

3.1.5 BUILDER'S TRIAL, CERTIFICATES OF FITNESS, AND CLASSIFICATION

For the Surface Emplacement, ROV Glider, and Direct Descent Disk vessels, costs for builder's trial,

certificate of fitness, and classification is based on a daily operational cost consisting of ships-force labor expenses and consumables. Labor expenses are based upon a total of nine persons/12 hour shift, 24 hours per day, at a labor cost of $55.00/MH. The consumable expenses primarily consist of fuel/oil cost, which are based upon a consumption rate of approximately 100 tons of fuel per day and 3 tons of oil per day. Labor expenses are therefore estimated at $11,880/day and consumable expenses at $14,425/day.

For the Pipe Riser, the Builder's Trial and Certificate of Fitness category was replaced with "On-site Assembly." This off-shore assembly will be done at the APWI site by approximately 18 people working 12 hour shifts each, 24 hours a day, for an estimated 20 days to assemble the riser and another 20 days to assemble the Spar Buoy. These assemblies will require the use of two leased Derrick Barges costing an estimated $200,000.00/day (similar to Global Industries DB-2 or DB-3 or OPI International DB #2).

3.1.6 PORT FACILITIES

Port facilities are required for loading sewage sludge and fly ash. These facilities are not needed for dredged material, as it is assumed transferred directly from the dredge to the APWI transport vessel. Port facilities costs include the automated bulk materials handling equipment, mixing equipment, storage facilities, fire and safety subsystems, and monitoring/compliance subsystems. Automated bulk materials handling equipment is needed to mechanically transfer and/or mix sewage sludge and municipal incinerator fly ash at 4800 metric tons per hour. This will require four 1200 metric tons/hr capacity mechanical loading lines connecting a bulk storage facility to four loading/feed points capable of being automatically positioned and connected to each of the cargo bay/cell locations aboard the vessel. This type loading system has an estimated net cost of $2.8 million (M), as summarized below:

- Four auger screw conveyor systems at $350,000 each:

  Dual feed auger screw conveyor system consisting of 15 each drive segments approximately 10 m long, with 16 IPS SCH 80 equivalent piping and integral hydraulic drive. At 50 pounds/foot assembled weight, and at a cost of approximately $6.00 per pound, each dual feed conveyor system would cost $0.3M, with an additional $0.05M for the 30 each hydraulic drive assemblies. The net estimated cost for the four conveyor systems is therefore equal to $1.4M.

- Four bridge crane assemblies at $320,000 each:

  75 metric ton live load capacity, having a span of approximately 50 m and a structural weight of approximately 100 metric tons. Using similar shipyard cost factors for material acquisition and manufacturing, at a net cost of $3520/metric ton, the estimated cost per crane assembly would be approximately $0.32M, or a net $1.28M. The batch-loading hopper assembly with operator platform is estimated at an additional cost of $0.12M. Total cost is therefore equal to $1.4M.

Ribbon blenders will be needed to mix sewage sludge and fly ash at port. Ribbon blenders are hoppers with a heavy shaft and paddles. Five of these blenders are needed at port to provide a mixing rate of 4800 metric tons/hour. Per Criterium DeSpain Engineering (Sewage Sludge Dewatering Facility Experts), these ribbon blenders will cost $500,000 each for a total of $2.5M per port.

The storage facilities for the port facility are sized to provide a total bulk storage for two vessel loading operations per day, or approximately 50,000 DWT capacity. This storage capacity is equivalent to approximately 40,000 m^3 (50,000 yd^3). Storage facility cost is estimated at \$8.8M, which includes cost for tank materials plus construction labor, based on shipbuilding rates of \$3520/ton X 2500 ton structural weight for 5 each 8,000 m^3 (10,000 yd^3) capacity tanks. Additionally, a budgetary cost of \$1M has been estimated for fire/safety subsystems, and a budgetary cost of \$1M is estimated for port monitoring /compliance control subsystems.

3.2 ANNUAL COSTS

Annual costs are the yearly operating costs for an APWI system and are comprised of the following:

- Amortized Capital Costs of Emplacement Concept,
- Amortized Capital Costs of Port Facilities,
- Operating Personnel,
- Fuel,
- Lube Oil,
- Consumables,
- Maintenance Spares, and
- Other Annual Costs.

These costs were based on the following assumptions and background information.

3.2.1 AMORTIZED CAPITAL COSTS OF EMPLACEMENT CONCEPT

The annual capital cost for APWI concepts is based on an eight year amortization schedule using an interest rate of 7.25%. The capital cost of the concept is comprised of the nonrecurring expenses of vessel design, shipyard production engineering manhours, material acquisition, and shipyard manufacturing manhours for a "new-build," builder's certification and certificates of fitness for transport vessels, and, if applicable, off-shore assembly (sections 3.1.1-3.1.5).

3.2.2 AMORTIZED CAPITAL COSTS OF PORT FACILITIES

The annual cost for "new build" port facilities is the capital cost of the port facilities equipment amortized over eight years at 7.25%. These capital costs include the cost of the automated bulk materials handling equipment, sewage sludge/fly ash mixing equipment, storage facilities, fire/safety subsystems, and associated monitoring/compliance control subsystems required (sections 3.1.6).

3.2.3 OPERATING PERSONNEL

For the port/dockside facilities, it is estimated that 18 persons/day will run the automated loading facility (six people per eight hour shift, 24 hours a day, seven days a week at a cost of $45/hr.

The oceangoing tug will require 18 persons/day (nine people each 12 hour shift), 24 hours a day, seven days a week at a cost of $55/hr.

3.2.4 FUEL/LUBE OIL

Costs for fuel and lube oil are based on JJMA provided values for a 25,000 DWT transporter operating at 15 knots and a transiting distance of 575 nautical miles (nmi) one way. The cost for diesel fuel is estimated at $40.00/nmi, and the cost of lube oil is estimated at $0.50/nmi.

3.2.5 CONSUMABLES

For APWI, consumables other than fuel and oil include ship's stores, geotextile bags, and transponders. Ship's stores costs were provided by JJMA based on a 25,000 DWT transporter operating at 15 knots and a round trip distance of 1150 nmi. Ships stores at 4.5 metric tons are estimated at $2700/trip.

Projected geotextile bag costs are estimated as follows:

- Surface Emplacement:
  $1183 for 400 m^3 (500 yd^3) capacity (600 square yards of fabric), 51 bags per trip, 95 trips per year.
- ROV Glider:
  $564 for 120 m^3 (160 yd^3) capacity (264 square yards of fabric), 153 bags per trip, 91 trips per year.

- Direct Descent Disk:
  \$162 for 22 m^3 (28.7 yd^3) capacity (86.4 square yards of fabric), 169 bags per disk, five disks per trip, 87 trips per year.

These values are based upon the current cost of geotextile bags having a 400 m^3 (500 yd^3) capacity. The material used in this bag is 37 m long by 14 m wide (120 ft by 45 ft) and costs \$11.50 per linear foot. These bags are currently being manufactured at the rate of 700 per year, at \$1380 per bag. Extrapolation to the much larger volumes of bags required for APWI is based upon application of the "Learning Curve," at a 95% figure-of-merit, yielding a 5% production cost reduction for every doubling of production volume, from the initial basis of 700 per year. Discussions with a geotextile manufacturer confirm this approach, and the use of the 95% value. A 95% figure-of-merit is considered to be very conservative, as typical production costs could be expected to reflect a 90% value. The present production techniques are very labor intensive, and future economies of scale would be based upon incorporation of automated production techniques. Additionally, because of thresholds on the learning curve, quantities were based upon doubling of quantities to permit maximum cost savings, thus the total quantity of waste stream capacity per year will vary for each different size category.

Disposable transponders are estimated to cost less than \$500 each, based upon annual production volumes of greater than 5000 per year, with budgetary quotation being provided by Benthos Inc.

3.2.6 MAINTENANCE/SPARES

The annual cost for maintenance and spares is based upon OTECH's experience. This cost is estimated at 1.5% to 3% of the amortized capital costs contained in section 3.2.1. The range is based on complexity.

3.2.7 OTHER COSTS

Other annual costs estimated in this exercise are docking fees and insurance. Docking fees, as confirmed by the Port of Baltimore, will run roughly \$1/foot of vessel/day. Insurance, assuming the vessel is separately insured, is based upon 0.5% of the capital cost when in port, and 1.5% of the capital cost when at sea.

4.0 RESULTS

Table 4.0-1 shows the Capital Costs of each element of an APWI system. The amortized capital costs are part of the total annual cost for the APWI concepts. Table 4.0-2 provides an APWI Summary of Costs for dredged material, sewage sludge, and municipal incinerator fly ash for each of the concepts. The total annual costs for each concept include the annual cost specific to that concept, annual port facility cost, annual tug cost, and, for the Pipe Riser, a barge cost (to transport material to the fixed site). This total was divided by the average annual tonnage emplaced for that specific concept to produce a cost per metric ton for sewage sludge and fly ash and a cost per cubic meter or cubic yard for dredged material.

Tonnages of waste emplaced for each concept were calculated first by examining the number of trips per year each system would complete. For this study, operational availability is assumed to be 100%.

LT + TT + ET + AF = HOURS/TRIP where;

- LT = Loading Time of a 25,000 DWT barge at 4800 tons/hour= 5.2 hours
- TT = Transit Time at 15 knots for an 1150 nautical mile round trip= 77 hours
- ET = Emplacement time specific for that system=
  - Surface Emplacement 2 hours
  - ROV Glider (includes operational 2x margin of safety) 6 hours
  - Direct Descent Disk (includes operational 2x margin of safety) 10 hours
  - Pipe Riser 12 hours
- AF = Adjustment Factor (estimated down time for various reasons)= 8 hours

From this formula the following trips per year were calculated for each concept:

- Surface Emplacement = 95 trips/year
- ROV Glider = 91 trips/year
- Direct Descent Disk = 87 trips/year
- Pipe Riser = 86 trips/year

For each trip, 25,000 DWT of material is transported, thus:

- Surface Emplacement = 2.38 million metric tons of material emplaced annually
- ROV Glider = 2.28 million metric tons of material emplaced annually
- Direct Descent Disk = 2.18 million metric tons of material emplaced annually
- Pipe Riser = 2.15 million metric tons of material emplaced annually

For dredged material, the cost is translated from a cost per metric ton to a cost per cubic yard basis which is consistent with current U.S. Army Corps of Engineers (COE) methods. One cubic yard of dredged material is equivalent to 1.063 metric tons. For each trip, 25,000 DWT, or 20,300 m^3 (26,600 yd^3), of material is transported, thus:

- Surface Emplacement = 1.93×10^6 m^3 (2.53×10^6 yd^3) of material emplaced annually
- ROV Glider = 1.86×10^6 m^3 (2.43×10^6 yd^3) of material emplaced annually
- Direct Descent Disk = 1.77×10^6 m^3 (2.32×10^6 yd^3) of material emplaced annually
- Pipe Riser = 1.75×10^6 m^3 (2.29×10^6 yd^3) of material emplaced annually

Also note that Port Facilities Annual Cost is not included in the total annual cost of dredged material emplacement because the desired operational scenario would require loading at the dredge site.

APWI – SUMMARY OF CAPITAL COSTS					
CONCEPT	CONCEPT CAPITAL COST (In Millions $)	PORT FACILITIES CAPITAL COST (In Millions $)	TUG CAPITAL COST (In Millions $)	BARGE CAPITAL COST (In Millions $)	TOTAL CAPITAL COST (In Millions $)
Surface Emplacement	45.21	17.71	31.91	n/a	94.83
ROV Glider	86.68	17.71	31.91	n/a	136.30
Direct Descent Disk	105.25	17.71	31.91	n/a	154.87
Pipe Riser	50.30	17.71	31.91	41.91	141.83

Table 4.0-1
APWI Summary of Capital Costs

APWI - SUMMARY OF ANNUAL COSTS Sewage Sludge and Fly Ash						
CONCEPT	CONCEPT ANN. COST (In Millions $)	PORT FACILITIES ANN. COST (In Millions $)	TUG ANN. COST (In Millions $)	BARGE ANN. COST (In Millions $)	TOTAL ANN. COST (In Millions $)	COST PER TON IN $ OF SEWAGE SLUDGE AND FLY ASH EMPLACED
Surface Emplacement	15.44	5.43	15.00	n/a	35.87	15
ROV Glider	24.79	5.43	14.80	n/a	45.02	20
Direct Descent Disk	32.48	5.43	14.60	n/a	52.51	24
Pipe Riser	11.38	5.43	14.56	8.23	39.60	18

APWI - SUMMARY OF COSTS Dredged Material						
CONCEPT	CONCEPT ANNUAL COST (In Millions $)	PORT FACILITIES ANN. COST (In Millions $)	TUG ANN. COST (In Millions $)	BARGE ANN. COST (In Millions $)	TOTAL ANN. COST (In Millions $)	COST PER CU YD OF DREDGED MATERIAL EMPLACED
Surface Emplacement	15.44	n/a	15.00	n/a	30.44	12
ROV Glider	24.79	n/a	14.80	n/a	39.59	16
Direct Descent Disk	32.48	n/a	14.60	n/a	47.08	20
Pipe Riser	11.38	n/a	14.56	8.23	34.17	15

Table 4.0-2
APWI Summary of Annual Costs

4.1 PORT FACILITIES

Tables 4.1-1 and 4.1-2 summarize the capital and annual costs respectively for the Port Facilities. The capital cost is estimated at $17.71M, with total annual cost estimated at $5.43M.

Concept: PORT FACILITIES – CAPITAL COSTS		
Category	Quantity	Total (Millions $)
1. Port Facilities Cost		
Automated Bulk Materials Handling	4 auger screw conveyor systems @ $350,000/system 4 bridge crane assemblies @ $320,000/assembly 1 batch–loading hopper @ $120,000/hopper	2.80
Storage Facility (50,000 cu yd Capacity)	2500Tons X $3520/Ton	8.80
Ribbon Blender	5 Ribbon Blenders @ $500,000/blender	2.50
Fire/Safety Subsystems	Budgetary cost	1.00
Monitoring/Compliance Subsystems	Budgetary cost	1.00
	Capital Cost Subtotal:	16.10
	Total Capital Cost with Typical Shipyard Profit:	17.71

Table 4.1-1
Port Facilities Capital Cost

Concept: PORT FACILITIES – ANNUAL COSTS		
Category	Quantity	Total/Yr (Millions $)
1. Amortization Cost (8 year at 7.25%, 1994$) Full Scale Operations (Port Facilities)	$17.71M X $165097/M	2.92
2. Operating Personnel Port/Dockside (6 people ea 8 hr shift, 24 hr/day, 365 day/yr @ $45.00/hr)	6 people	2.37
3. Maintenance/Spares	est 3.0% of #1	0.07
4. Insurance	Port = .5% Capital	0.07
	Total Annual Cost:	5.43

Table 4.1-2
Port Facilities Annual Costs

4.2 TUG

Tables 4.2-1 and 4.2-2 summarize the capital and annual costs respectively for the Tug. Consumables such as fuel, lube oil, and ship's stores vary between concepts because they are dependent upon the number of trips made in a year. For this reason, these costs are shown on a per concept basis. The capital cost is identical regardless of the concepts and is estimated at $31.91M. Annual cost for the tug is estimated at $15.00M for Surface Emplacement, $14.80M for ROV Glider, $14.60M for the Direct Descent Disk, and $14.56M for the Pipe Riser.

Concept: TUG - CAPITAL COSTS		
Category	Quantity	Total (Millions $)
1. Design Cost	7,200 MH X $60.00/MH	0.43
2. Shipyard Production Engineering Cost		
Engineering Manhours (Self-Powered Modified Variant)	72,000MH X $33.60/MH	2.42
Engineering Manhours (Unmanned ITB or Other)	n/a	0.00
3. Material Acquisition Cost		
Steel	2400 Tons X $1000/Ton	2.40
Aluminum	n/a	0.00
Foam	n/a	0.00
Propulsion & Electric Plant	800 Tons X $5500/Ton	4.40
Electronic Subsystems	$0.25M/System	0.25
Fluid Systems (10% of Outfit)	200 Tons X $2500/Ton	0.50
Remainder of Outfit	300 Tons X $3000/Ton	0.90
4. Shipyard Manufacturing Cost		
Structural	2400 Tons X 75 MH/Ton X $33.60/MH	6.05
Machinery Installation	800 Tons X 200MH/Ton X 33.60/MH	5.38
Fluid Systems Installation	200 Tons X 250MH/Ton X 33.60/MH	1.68
Remainder of Outfit	930 Tons X 150MH/Ton X 33.60/MH	4.60
5. Builder's Trial(s) and Certificate of Fitness	n/a (Included under ITB Trials)	0.00
	Capital Cost Subtotal:	29.01
	Total Capital Cost with Typical Shipyard Profit:	31.91

Table 4.2-1
Tug Capital Costs

Concept: TUG - ANNUAL COSTS		
Category	Quantity	Total/Yr (Millions $)
1. Amortization Cost (8 year at 7.25%, 1994$)		
Full Scale Operations (Open Ocean Vessels)	$31.91M X $165097/M	5.27
Full Scale Operations (Port Facilities)	n/a	0.00
2. Operating Personnel		
Port/Dockside		
6 people ea 8hr shift , 24hrday, 365day/yr @ $45.00/hr)	n/a	0.00
Open Ocean Vessels (9 people ea 12hr shift , 24hr/day, 365day/yr @ $55.00/hr)	9 people	4.30
3. Diesel Fuel	1150 Nm X $40.00/Nm = $46,000/Trip	
Surface Emplacement	$46,000/Trip X 95 Trips/Yr	4.37
ROV Glider	$46,000/Trip X 91 Trips/Yr	4.18
Direct Descent Disk	$46,000/Trip X 87 Trips/Yr	4.00
Pipe Riser	$46,000/Trip X 86 Trips/Yr	3.96
4. Lube Oil	1150 Nm X $0.50/Nm = $575/Trip	
Surface Emplacement	$575/Trip X 95 Trips	0.05
ROV Glider	$575/Trip X 91 Trips	0.05
Direct Descent Disk	$575/Trip X 87 Trips	0.05
Pipe Riser	$575/Trip X 86 Trips	0.05
5. Consumables		
Stores	$2700/Trip	
Surface Emplacement	$2700/Trip X 95 Trips	0.26
ROV Glider	$2700/Trip X 91 Trips	0.25
Direct Descent Disk	$2700/Trip X 87 Trips	0.23
Pipe Riser	$2700/Trip X 86 Trips	0.23
Geotextile Bags	n/a	0.00
Transponders	n/a	0.00
6. Maintenance/Spares	est 3% of #1	0.13
7. Other		
Docking Fees	240 ft X $1.00/ft/day	0.09
Insurance (Port)	Port = .5% Capital	0.13
Insurance (Sea)	Sea = 1.5% Capital	0.40
	Total Annual Cost:	
	Surface Emplacement:	15.00
	ROV Glider:	14.80
	Direct Descent Disk:	14.60
	Pipe Riser:	14.56

Table 4.2-2
Tug Annual Costs

4.3 BARGE

Since the Pipe Riser concept is a permanent offshore fixture, a bulk-carrying barge will be needed to transport the materials from the port facility to the Pipe Riser. Tables 4.3-1 and 4.3-2 summarize the capital and annual costs respectively for this 25,000 DWT barge. The capital cost is estimated at \$41.91M, with a total annual cost of \$8.23M.

Concept: BARGE - CAPITAL COSTS		
Category	Quantity	Total (Millions \$)
1. Design Cost	15,000MH X \$60.00/MH	0.90
2. Shipyard Production Engineering Cost		
Engineering Manhours (Self-Powered or SSP)	n/a	0.00
Engineering Manhours (Unmanned ITB or Other)	50,000MH X \$33.60/MH	1.68
3. Material Acquisition Cost		
Steel	7650 Tons X \$1000/Ton	7.65
Aluminum	n/a	0.00
Foam	n/a	0.00
Propulsion & Electric Plant	n/a	0.00
Fluid Systems (10% of Outfit)	100 Tons X \$2500/Ton	0.25
Remainder of Outfit	900 Tons X \$3000/Ton	2.70
4. Shipyard Manufacturing Cost		
Structural	7650 Tons X 75 MH/Ton X \$33.60/MH	19.28
Machinery Installation	n/a	0.00
Fluid Systems Installation	100 Tons X 250MH/Ton X \$33.60/MH	0.84
Remainder of Outfit	900 Tons X 150MH/Ton X \$33.60/MH	4.54
5. Builder's Trial(s) and Certificate of Fitness Employs 9 people/12hr shift, 24hr/day, @ \$55.00/hr	Daily Operational Costs for 10 days: Labor = \$11,880/day X 10 days Fuel/Oil = \$14,425/day X 10 days	0.26
	Capital Cost Subtotal:	38.10
	Total Capital Cost with Typical Shipyard Profit:	41.91

Table 4.3-1
Barge Capital Costs

Concept: BARGE - ANNUAL COSTS		
Category	Quantity	Total/Yr (Millions $)
1. Amortization Cost (8 year at 7.25%, 1994$) Full Scale Operations (Open Ocean Vessels)	$41.91 X $165097/M	6.92
2. Operating Personnel Port/Dockside (6 people ea 8hr shift, 24hrs/day, 365day/yr @$45.00/hr)	n/a (ref port facilities)	0.00
Open Ocean Vessels (9 people ea 12hr shift, 24 hrs/day, 365day/yr @$55.00/hr)	n/a (ref tug)	0.00
3. Diesel Fuel	n/a (ref tug)	0.00
4. Lube Oil	n/a (ref tug)	0.00
5. Consumables Stores	n/a (ref tug)	0.00
Geotextile Bags (500 cubic yard capacity)	n/a	0.00
Transponders	n/a	0.00
6. Maintenance/Spares	est 1.5% of #1	0.10
7. Other Docking Fees	1000 ft X $1.00/ft/day, 365 day/yr	0.37
Insurance (Port)	Port = .5% Capital	0.21
Insurance (Sea)	Sea = 1.5% Capital	0.63
	Total Annual Cost:	8.23

Table 4.3-2
Barge Annual Costs

4.4 SURFACE EMPLACEMENT

Tables 4.4-1 and 4.4-2 summarize the capital and annual costs respectively for the Surface Emplacement concept. Total capital cost is estimated at $45.21M, with total annual cost estimated at $15.44M. A net annual cost for the Surface Emplacement concept must also include both Port Facilities and Tug annual costs. Port Facilities capital and annual costs respectively were summarized in Tables 4.1-1 and 4.1-2. The Tug cost was summarized in Tables 4.2-1 and 4.2-2.

Concept: SURFACE EMPLACEMENT - CAPITAL COSTS		
Category	Quantity	Total (Millions $)
1. Design Cost	15,000MH X $60.00/MH	0.90
2. Shipyard Production Engineering Cost		
Engineering Manhours (Self-Powered or SSP)	n/a	0.00
Engineering Manhours (Unmanned ITB or Other)	50,000MH X $33.60/MH ($3.0 M added for Hull Doors)	4.68
3. Material Acquisition Cost		
Steel	7650 Tons X $1000/Ton	7.65
Aluminum	n/a	0.00
Foam	n/a	0.00
Propulsion & Electric Plant	n/a	0.00
Fluid Systems (10% of Outfit)	100 Tons X $2500/Ton	0.25
Remainder of Outfit	900 Tons X $3000/Ton	2.70
4. Shipyard Manufacturing Cost		
Structural	7650 Tons X 75 MH/Ton X $33.60/MH	19.28
Machinery Installation	n/a	0.00
Fluid Systems Installation	100 Tons X 250MH/Ton X $33.60/MH	0.84
Remainder of Outfit	900 Tons X 150MH/Ton X $33.60/MH	4.54
5. Builder's Trial(s) and Certificate of Fitness Employs 9 people/12hr shift, 24hr/day, @$55/hr	Daily Operational Costs for 10 days: Labor = $11,880/day X 10 days Fuel/Oil = $14,425/day X 10 days	0.26
	Capital Cost Subtotal:	41.10
	Total Capital Cost with Typical Shipyard Profit:	45.21

Table 4.4-1
Surface Emplacement Capital Cost

Concept: SURFACE EMPLACEMENT - ANNUAL COSTS		
Category	**Quantity**	**Total/Yr (Millions $)**
1. Amortization Cost (8 year at 7.25%, 1994$) Full Scale Operations (Open Ocean Vessels)	$45.21M X $165097/M	7.46
2. Operating Personnel Port/Dockside (6 people ea 8 hr shift, 24 hr/day, 365 day/yr @ $45.00/hr	n/a (see port facilities)	0.00
Open Ocean Vessels (9 people ea 12hr shift, 24 hr/day, 365 day/yr @$55/hr)	n/a	0.00
3. Diesel Fuel	n/a (ref tug)	0.00
4. Lube Oil	n/a (ref tug)	0.00
5. Consumables Stores	n/a (ref tug)	0.00
Geotextile Bags (500 cubic yard capacity)	4845 bags/year $1,183/bag	5.73
Transponders	1710 transponders/yr $500.00/transponder	0.86
6. Maintenance/Spares	est 1.5% of #1	0.11
7. Other Docking Fees	1000ft X $1.00/ft/Day	0.37
Insurance (Port)	Port = .5% Capital	0.23
Insurance (Sea)	Sea = 1.5% Capital	0.68
	Total Annual Cost:	15.44

Table 4.4-2
Surface Emplacement Annual Cost

4.5 ROV GLIDER

Tables 4.5-1 and 4.5-2 summarize the capital and annual costs respectively for the ROV Glider concept. Total capital cost is estimated at $86.68M, with total annual cost estimated at $24.79M. A net annual cost for the ROV Glider concept must also include both Port Facilities and Tug annual costs. Port Facilities costs were summarized in Tables 4.1-1 and 4.1-2. The Tug costs were summarized in Tables 4.2-1 and 4.2-2.

Concept: ROV GLIDER - CAPITAL COSTS				
Category	Quantity	ROV (Millions $)	Launcher (Millions $)	Total (Millions $)
1. Design Cost	R = 66,000MH X $60.00/MH L = 33,000MH X $60.00/MH	3.96	1.98	5.94
2. Shipyard Production Engineering Cost Engineering Manhours (Self-Powered or SP)	n/a	0.00	0.00	0.00
Engineering Manhours (Unmanned ITB or Other)	R = 50,000MH X $33.60/MH L = 50,000MH X $33.60/MH	1.68	1.68	3.36
3. Material Acquisition Cost Steel	L = 7650T X $1000/T	0.00	7.65	7.65
Aluminum	R = 2400T X $2500/T	6.00	0.00	6.00
Foam (High Density)	R = 1360T X $14700/T	19.99	0.00	19.99
Propulsion & Electric Plant	R = 7T X $25000/T	0.18	0.00	0.18
Electronic Subsystems	R = 1 SYS X $1M/SYS L = 1 SYS X $0.25M/SYS	1.00	0.25	1.25
Fluid Systems	R = 5T X $2500/T L = 100T X $2500/T	0.01	0.25	0.26
Remainder of Outfit	L = 900T X $3000/T	0.00	2.70	2.70
4. Shipyard Manufacturing Cost Structural	R = 2400T X 75MH/T X $33.60/MH L = 7650T X 75MH/T X $33.60/MH	6.05	19.28	25.33
Machinery Installation	R = 5T X 200MH/T X $33.60/MH L = 25T X 200MH/T X $33.60/MH	0.03	0.17	0.20
Fluid Systems Installation	R = 5T X 250MH/T X $33.60/MH L = 100T X 250MH/T X $33.60/MH	0.04	0.84	0.88
Remainder of Outfit	L = 900T X 150MH/T X $33.60/MH	0.00	4.54	4.54
5. Builder's Trial(s) & Certificate of Fitness Employs 9 people 12 hr shift, 24 hr/day @ $55.00/hr	Daily Operating Cost: Labor = 20 Days X $11,880/day Fuel/Oil = 20 Days X $14,425/Day	0.26	0.26	0.52
	Capital Cost Subtotal:	39.20	39.60	78.80
	Total Capital Cost with Typical Shipyard Profit:	43.12	43.56	86.68

R = ROV
L = Launcher

Table 4.5-1
ROV Glider Capital Cost

Concept: ROV GLIDER - ANNUAL COSTS

Category	Quantity	ROV (Millions $)	Launcher (Millions $)	Total/Yr (Millions $)
1. Amortization Cost (8 year at 7.25%, 1994$) Full Scale Operations (Open Ocean Vessels)	R = $43.12M X $165097/M L = $43.56M X $165097/M	7.12	7.19	14.31
2. Operating Personnel				
Port/Dockside (6 people ea 8 hr shift, 24 hr/day, 365 day/yr @ $45.00/hr)	n/a (ref port facilities)	0.00	0.00	0.00
Open Ocean Vessels (9 people ea 12 hr shift, 24 hr/day, 365 day/yr @ $55.00/hr)	n/a (ref tug)	0.00	0.00	0.00
3. Diesel Fuel	n/a (ref tug)	0.00	0.00	(included w/tug)
4. Lube Oil	n/a (ref tug)	0.00	0.00	(included w/tug)
5. Consumables				
Stores	n/a (ref tug)	0.00	0.00	(included w/tug)
Geotextile Bags (166 cubic yard capacity)	13,923 bags/year $564.00/Bag	7.85	0.00	7.85
Transponders	182 transponders/year $500.00/transponder	0.09	0.00	0.09
6. Maintenance/Spares	est 3% of #1	0.21	0.22	0.43
7. Other				
Docking Fees	1000ft X $1.00/ft/day	0.00	0.37	0.37
Insurance (Port)	Port = .5% Capital	0.22	0.22	0.44
Insurance (Sea)	Sea = 1.5% Capital	0.65	0.65	1.30
	Total Annual Cost:	16.14	8.65	24.79

Table 4.5-2
ROV Glider Annual Cost

4.6 DIRECT DESCENT DISK

Tables 4.6-1 and 4.6-2 summarize the capital and annual costs respectively for the Direct Descent Disk concept. Total capital cost is estimated at $105.25M ($21.05M/disk X 5 disks), with total annual costs estimated at $32.48M. A net annual cost for the Direct Descent Disk concept must also include both Port Facilities and Tug annual costs. Port Facilities costs were summarized in Tables 4.1-1 and 4.1-2. The Tug costs were summarized in Tables 4.2-1 and 4.2-2.

Concept: DIRECT DESCENT DISK CAPITAL COSTS				
Category	**Quantity**	**Disk (Millions $)**	**Floater (Millions $)**	**Total (Millions $)**
1. Design Cost	D = 7,500MH X $60.00/MH F = 17,500MH X $60.00/MH	0.45	1.05	1.50
2. Shipyard Production Engineering Cost Engineering Manhours (Self-Powered or SP)	n/a	0.00	0.00	0.00
Engineering Manhours (Unmanned ITB or Other)	D = 24,800MH X $33.60/MH F = 50,200MH X $33.60/MH	0.83	1.68	2.51
3. Material Acquisition Cost Steel	F = 330T X $1000/T	0.00	0.33	0.33
Aluminum	D = 468T X $2500/T	1.17	0.00	1.17
Foam	D = 502T X $14700/T	7.38	0.00	7.38
Propulsion & Electric Plant	D = 2.5T X $25000/T F = 30T X $5500/T	0.63	0.17	0.80
Electronic Subsystems	D = 1 SYS X $.25M/SYS F = 1 SYS X $.45M/SYS	0.25	0.45	0.70
Fluid Systems	D = 8T X $2500/T F = 30T X $2500/T	0.02	0.08 0.00	0.10
Remainder of Outfit	F = 40T X $3000/T	0.00	0.12	0.12
4. Shipyard Manufacturing Cost Structural	D = 970T X 75MH/T X $33.60/MH F = 330T X 75MH/T X $33.60/MH	2.44	0.83	3.27
Machinery Installation	D = 2.5T X 200MH/T X $33.60/MH F = 30T X 200MH/T X $33.60/MH	0.02	0.20	0.22
Fluid Systems Installation	D = 8T X 250MH/T X $33.60/MH F = 30T X 250MH/T X $33.60/MH	0.07	0.25	0.32
Remainder of Outfit	F = 40T X 150MH/T X $33.60/MH	0.00	0.20	0.20
5. Builder's Trial & Certificate of Fitness Employs 9 people 12 hr shift, 24 hr/day @ $55.00/hr	Daily Operating Cost for 20 Days Labor = $11,880/day X 20 days Fuel/Oil = $14,425/day X 20 days	0.26	0.26	0.52
	Capital Cost Subtotal:	13.52	5.62	19.14
	Total Capital Cost with Typical Shipyard Profit:	14.87	6.18	21.05

D = Disk
F = Floater

Table 4.6-1
Direct Descent Disk Capital Cost

Concept: DIRECT DESCENT DISK - ANNUAL COSTS				
Category	Quantity	Disk (Millions $)	Floater (Millions $)	Total/Yr (Millions $)
1. Amortization Cost (8 year at 7.25%, 1994$) * Full Scale Operations (Open Ocean Vessels)	D = $74.35M X $165097/M F = $30.9M X $165097/M	12.27	5.10	17.37
2. Operating Personnel				
Port/Dockside (6 people ea 8hr shift, 24 hr/day, 365 day/yr @ $45.00/hr)	n/a (ref port facilities)	0.00	0.00	0.00
Open Ocean Vessels (9 people ea 12hr shift, 24hr/day, 365day/yr @ $55.00/hr)	n/a (ref tug)	0.00	0.00	0.00
3. Diesel Fuel	n/a (ref tug)	0.00	0.00	0.00
4. Lube Oil	n/a (ref tug)	0.00	0.00	0.00
5. Consumables				
Stores	n/a (ref tug)	0.00	0.00	0.00
Geotextile Bags (38 cubic yard capacity)	73,515 bags/year $162.00/bag	11.90	0.00	11.90
Transponders	435 transponder/yr $500.00/transponder	0.22	0.00	0.22
6. Maintenance/Spares	est. 3% of #1	0.37	0.15	0.52
7. Other				
Docking Fees	1000ft X $1.00/ft/day	0.00	0.37	0.37
Insurance (Port)	Port = .5% Capital	0.37	0.15	0.52
Insurance (Sea)	Sea = 1.5% Capital	1.12	0.46	1.58
	Total Annual Cost:	26.25	6.23	32.48

* Calculated for 5 floater disk modules

D = Disk
F = Floater

Table 4.6-2
Direct Descent Disk Annual Cost

4.7 PIPE RISER

Tables 4.7-1 and 4.7-2 summarize the capital and annual costs respectively for the Pipe Riser concept. Total capital cost is estimated at $50.30M, with total annual cost estimated at $11.38M. A net annual cost for the Pipe Riser concept must also include Port Facilities, Tug, and Barge annual costs. Port Facilities costs were summarized in Tables 4.1-1 and 4.1-2, the Tug costs were summarized in Tables 4.2-1 and 4.2-2, and the Barge costs were summarized in Table 4.3-1 and 4.3-2. The barge referenced with this concept is a standard design bulk cargo barge. This barge is required to transport the waste to the Pipe Riser system at sea.

Concept: PIPE RISER - CAPITAL COSTS				
Category	**Quantity**	**Riser (Millions $)**	**S. Buoy (Millions $)**	**Total (Millions $)**
1. Design Cost	R = 16,500MH X $60.00/MH SB = 16,500MH X $60.00/MH	0.99	0.99	1.98
2. Shipyard Production Engineering Cost Engineering Manhours (Self-Powered or SP)	n/a	0.00	0.00	0.00
Engineering Manhours (Unmanned ITB or Other)	R = 16,500MH X $33.60/MH SB = 50,000MH X 33.60/MH	0.55	1.68	2.23
3. Material Acquisition Cost Steel	SB = 2500T X $1000/T	0.00	2.50	2.50
Driscopipe	R = 3400T X $3060/T	10.40	0.00	10.40
Concrete or Gel Ballast	sb = 2500T X $100/T	0.00	0.25	0.25
Propulsion & Electric Plant	SB = 500T X $5500/T	0.00	2.75	2.75
Electronic Subsystems	SB = 1 SYS X $.45M/SYS	0.00	0.45	0.45
Fluid Systems	SB = 50T X $2500/T	0.00	0.13	0.13
Remainder of Outfit	R = 340T X $3000/T SB = 300T X $3000/T	1.02	0.90	1.92
4. Shipyard Manufacturing Cost Structural	R = 340T X 75MH/T X $33.60/MH SB = 2500T X 75MH/T X $33.60/MH	0.86	6.30	7.16
Machinery Installation	SB = 500T X 200MH/T X $33.60/MH	0.00	3.36	3.36
Fluid Systems Installation	SB = 50T X 250MH/T X $33.60/MH	0.00	0.42	0.42
Remainder of Outfit	R = 340T X 150MH/T X $33.60/MH SB = 300T X 150MH/T X $33.60MH	1.71	1.51	3.22
5. On-site assembly Employs 18 people 12 hr shift, 24 hr/day @ $55.00/hr	Daily Operational Cost Labor: R = $23,760/day X 20 days SB = $23,760/day X 20 days Derrick Barge lease @ $200,000/day X 40 days	0.48 4.00	0.48 4.00	0.96 8.00
	Capital Cost Subtotal:	20.01	25.72	45.73
	Total Capital Cost with Typical Shipyard Profit:	22.01	28.29	50.30

R = Riser
SB = Spar Buoy

Table 4.7-1
Pipe Riser Capital Cost

Concept: PIPE RISER - ANNUAL COSTS

Category	Quantity	Riser (Millions $)	S. Buoy (Millions $)	Total/Yr (Millions $)
1. Amortization Cost (8 year at 7.25%, 1994$) Full Scale Operations (Open Ocean Vessels)	R = $22.01M X $165097/M SB = 28.29 M X $165097/M	3.63	*see note 5.35	8.98
2. Operating Personnel				
Port/Dockside (6 people ea 8hr shift, 24 hr/day, 365 day/yr @ $45.00/hr)	n/a (ref barge)	0.00	0.00	0.00
Open Ocean Vessels (9 people ea 12 hr shift, 24 hr/day, 365 day/yr @ $55.00/hr)	n/a (ref tug)	0.00	0.00	0.00
3. Diesel Fuel (Thrusters, Pumps, Etc.)	Generator 5500HP @ $150.00/hr 24 hr/day, 365 day/yr	0.00	1.31	1.31
4. Lube Oil (Thrusters, Pumps, Etc.)	$7.50/hr 24 hr/day, 365 day/yr	0.00	0.07	0.07
5. Consumables				
Stores	n/a (ref tug)	0.00	0.00	0.00
Geotextile Bags	n/a	0.00	0.00	0.00
Transponders	n/a	0.00	0.00	0.00
6. Maintenance/Spares	est 3% of #1	0.11	0.16	0.27
7. Other				
Docking Fees	n/a	0.00	0.00	0.00
Insurance (Port)	Port (N/A)	0.00	0.00	0.00
Insurance (Sea)	Sea = 1.5% Capital	0.33	0.42	0.75
	Total Annual Cost:	4.07	7.31	11.38

* Includes added seabed tractor expense of $0.68M

R = Riser
SB = Spar Buoy

Table 4.7-2
Pipe Riser Annual Cost

5.0 DEVELOPMENT COST ESTIMATES

Prior to full scale operation of any of these APWI concepts, prototype systems would be developed and tested to quantify both technical and environmental issues. To have a complete picture of the total system cost of any concept, the development costs associated with the analysis, design, prototype build and testing must be considered.

Figure 5.0-1 illustrates the chronological flow of a project that is initially sponsored by government funding and then transitions to commercialization. As depicted in this figure, the government would be funding the effort to demonstrate technical feasibility and industry would fund the full scale design, fabrication and operation of the system. The cost figures presented in preceding sections of this report detail the full scale system construction and operation costs borne by industry, while the cost estimates in this section are those associated with government sponsored development costs.

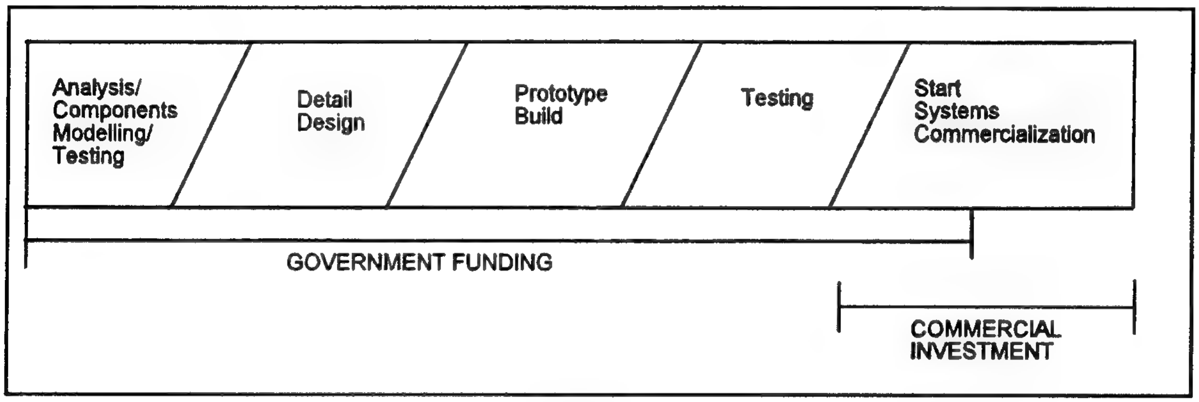

Figure 5.0-1
Chronological Flow of a Government/Industry Development Program

As discussed in the Technical Assessment Report for Abyssal Plains Waste Isolation Project (Hightower et al., in publication), each concept has its own set of technical issues and risks. Shown below in Table 5.0-1, are cost estimates for each of the four APWI concepts for the various development stages.

CONCEPT	COMPONENT TESTING	DETAIL DESIGN	PROTOTYPE BUILD	TESTING/ MODS	TOTAL
SURFACE EMPLACEMENT	1 - 5 M	N/A	N/A	N/A	1 - 5 M
ROV GLIDER	1 - 5 M	3 - 6 M	15-25M	1 - 5 M	20-41 M
DIRECT DESCENT DISK	1 - 5 M	3 - 6 M	15-25M	1 - 5 M	20-41 M
PIPE RISER	5 - 15M	4 - 8 M	45-75M	3 - 10M	57-108M

Table 5.0-1
Development Cost Estimates ($M)

The rationale for the above cost figures are explained below:

■ Surface Emplacement: There are two primary technical issues to verify in order to validate this approach:

- bag hydrodynamic stability during free-fall (needs modelling/testing) and
- reliability of fabric bags for containerization, especially regarding potential for bag tearing as it falls through the cell trap door.

It is anticipated that, through analysis and computer modelling/simulation of bag hydrodynamic stability and component testing of bags and trap doors, the above issues can be resolved. The cost estimate for Analysis/Component Testing is based on OTECH's experience developing and testing marine application hardware. After these issues are successfully resolved, this concept is ready for full scale design. This statement is predicated on the premise that this design is a modification of existing equipment and no intermediate scale models are necessary to verify this concept.

■ ROV Glider: The ROV Glider has several technical issues to address/resolve prior to transitioning to a commercially viable system. In summary, they are:

- hydrodynamic characterization of the vehicle
- controllability of the vehicle
- reliable cargo release
- launch and recovery of the vehicle

In order to resolve these issues, all facets of the development cycle would be needed. Analysis and modelling would be used to characterize hydrodynamics and control system issues. In addition, a fully functional scaled model would be required to verify the analysis results and to validate operational procedures. Therefore, detailed design of a scaled model, prototype fabrication, and functional and operational testing would be required. The associated cost estimates are again based on OTECH's experience developing and testing marine hardware.

■ Direct Descent Disc: The Direct Descent Disc has basically the same issues as the ROV Glider and therefore the estimated development costs fall within the same range as the Glider.

■ Pipe Riser System: The Pipe Riser has many technical and operational issues to resolve in order to verify its reliability including:

- catenary analysis of the pipe bundle
- station keeping of the surface platform
- dilution flow monitoring/control of the waste stream
- pipe riser installation procedure
- pipe riser dynamic response
- reliability of sea bed tractors/mobile gravity anchors
- operational considerations: manned versus unmanned; at-sea maintenance; and interface w/ transport ship

Most of these issues can be analyzed and/or modelled as the first step in concept validation. The cost estimate for this Analysis/Modelling phase is based on relative complexity when compared to the submersible designs. Given the nature of the technical issues associated with this concept, it is assumed that a scaled physical model will not adequately validate the critical issues. For example, many of the above issues revolve around large diameter pipes installed in deep water. Performing tests of some reduced scale model in shallower water will not necessarily produce scalable results. Certainly, some operational considerations are not scalable, such as installing 600 meters of pipe in shallow water is totally different from installing 6000 meters of pipe in deep water. Therefore the conclusion is that a full scale, fully operational pipe riser system would have to be designed, built, installed, and tested as the development system. The costs associated with Detailed Design and Prototype Build are then tied to the capital costs estimated for a production system as described in section 4.7 of this report. The Testing cost estimate is based on relative complexity when compared to the submersible designs.

6.0 CONCLUSIONS

Table 6.0-1. Summary of Emplacement Costs (from Table 4.0-2)

Concept	Cost for sewage sludge and fly ash ($/metric ton)	Cost for dredged material ($/unit volume)
Surface Emplacement	15	$16/m^3$ ($12/yd^3$)
ROV Glider	20	$21/m^3$ ($16/yd^3$)
Direct Descent Disk	24	$26/m^3$ ($20/yd^3$)
Pipe Riser	18	$20/m^3$ ($15/yd^3$)

Comparison of the annual emplacement costs per amount of material emplaced (Table 6.0-1) is surprisingly similar for all of the concepts, and indicates that, regardless of the concept, the cost/ton is within $9/ton for sewage sludge and fly ash, and $10/cubic meter ($8/cubic yard) for dredged material. The similarity in costs between concepts is dominated by two factors:

(1.) The volume of emplaced waste is so large that variances in capital costs have little effect on the price of isolation per ton of material emplaced. For every $25 million increment in capital cost, the effect on emplacement cost is less than $2.00/ton. For example, the annual cost impact of $25 million dollars is $4.23 million/yr (amortized over eight years, at 7.25%). This impact on Surface Emplacement would then be: $4.23M / 2.38x10^6 metric tons = $1.78/metric ton (see Tables 4.4-1 and 4.4-2).

(2.) The operating costs for each of the systems are basically the same.

Another significant result is that the disposable bag accounts for an average 20% of the emplacement cost. For example, per Table 4.0-1, the ROV Glider's Total Annual Cost is $45.02M with annual disposable bag cost of $7.85M (Table 4.5-2), or 17% of its Total Annual Cost. In any commercialized system with a significant single cost driver, such as the bag would be, efforts would be spent on lowering this specific cost. Therefore, in full scale operations, the bag cost would be reduced either through design changes or manufacturing economies of scale.

7.0 REFERENCES

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